Quarterly Progress Report for Contract N00014-90-J-1599

"Modeling Physical Objects"

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1 Summary of Activities

The Newton work concentrated on increasing the robustness of both the simulator and the geometric processor (ProtoSolid). The handling of persistent contacts was addressed in particular. The implemention was carried out by Bill Bouma and Dr. George Vaněček. For technical details see Section 2.1. The geometry research continued developing the basic theory and infrastructure for constraint-based surface design using the dimensionality paradigm. In addition, it entered a new phase with application work on the skeleton of CSG objects. For technical details see Section 2.2.

The reports and papers completed during the reporting period are listed below in Section 2.4. I participated in teaching the SIGGRAPH '90 course on unifying parametric and implicit curve and surface representations. In September, I gave an invited presentation at the fourth IMA conference "The Mathematics of Surfaces" in Bath, England. At the ASME confernce on design automation Debasish Dutta from the Mechanical Engineering Department of the University of Michigan and I made a contributed presentation. I also served on the panel evaluating the progress of the ONR-URI project at the University of North Carolina, Chapel Hill. See also Section 2.3

2 Technical Details of the Work

2.1 Mechanical Simulation

We conducted experiments with chains of linked rings, and learned that temporary contacts that persist over a longer period of time break the system. The problems were tracked down to two sources. First, the simulator component used single-precision floating-point numbers, whereas ProtoSolid, the geometry component, used double-precision. Secondly, shallow penetrations at small angles caused problems in that the B-rep index had the tendency to report contacts between faces when contacts between edges would have been more meaningful.

The first source of trouble was fixed easily, thanks to the fact that the language in which Newton is implemented (Common Lisp) makes the change to double-precision very easy. The second source of problems was of a fundamental nature and relates to the accuracy problems geometric computations have when using floating-point arithmetic. We spent a large part of our efforts developing concepts for restructuring the B-rep index data structure in such a way that its robustness is increased while not losing efficiency.

By carefully considering the geometry of small interpenetrations and the effect of ϵ tolerances, we were able to perfect the robustness of the B-rep index. We plan to put together a video tape demonstrating the capabilities Newton now has, and show some of the simulations that are quite impossible using conventional approaches to simulation.

2.2 Geometry Research

Work continues to develop the dimensionality paradigm. In view of the difficulty of solving general systems of algebraic equations, we concentrated on applications in which the complexity of the problem can be limited a-priori. Such an application is the skeleton (medial-axis transform) of three-dimensional solid domains specified with help of constructive solid geometry from the standard primitives, i.e., from block, cylinder, cone, sphere, and torus. The skeleton can be defined as the locus of the centers of all maximal inscribed spheres. Maximal means that no sphere is properly contained in another inscribed sphere.

According to work by Patrikalakis and Gursoy from MIT's Sea Grant College, the skeleton has important applications in finite-element mesh generation, a basic need of many analysis codes. Other applications include motion planning and computer vision. Prior work has concentrated almost exclusively on the two-dimensional problem. The reasons are not difficult to identify: The surface types arising even with simple curved surfaces such as cylinders and spheres include some very difficult mathematical surfaces, and the field simply did not have the necessary tools to build such surfaces systematically.

The dimensionality paradigm does provide in principle the needed methodology for expressing the complex surfaces of the three-dimensional skeleton. The prior work with Jung-Hong Chuang, moreover, provided the infrastructure for giving uniform local and global surface approximations. Coupled with methods to derive initial points, therefore, the skeleton problem becomes tractable. For CSG primitives, however, the initial points problem is tractable. Thus, Ching-Shoei Chiang has initiated work to develop a complete implementation. This work is also of interest to the NSF Engineering Research Center here at Purdue, and we plan to integrate our implementation with some of their automated manufacturing software.

With Pamela Vermeer I continue the work on the faithfulness problem. She is also studying methods to analyze under what circumstances surfaces in n-space might project to surfaces with singularities such as self-intersections that are not present in the preimage.

Neelam Jasuja joined the group. She is looking at the miscellaneous problems including parametric blending, and whether the skeleton is a convenient solid representation.

2.3 Talks, Workshops and Conferences

At the fourth IMA conference "The Mathematics of Surfaces" in Bath, England, I presented the algorithm for skeleton construction in an invited talk. A potentially very useful result presented at the conference is a criterion by Milne (Bath) for determining whether a given volume in 3-space contains a real component of an irreducible algebraic surface. The proceedings of the conference will be published by Oxford University Press.

At the ASME Conference on Design Automation in Chicago, D. Dutta and I presented joint work on the surface geometries arising in the skeleton of CSG objects.

2.4 Reports and Publications

1. "Conversion Methods between Parametric and Implicit Curves and Surfaces," Rept. CER-90-18, April 1990.

2. "A Geometric Investigation of the Skeleton of CSG Objects," *Proc. ASME Conf. Design Automation*, Chicago, 1990; (with D. Dutta).

3. "How to Construct the Skeleton of CSG Objects," *Proc.* 4^{th} *IMA Conf. Math. of Surfaces*, Oxford University Press, 1991.

4. Jung-Hong Chuang, "Surface Approximations in Geometric Modeling," PhD Diss., Dept. of Comp. Sci., Purdue University; Rept. CER-90-37, September 1990.